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The Human Packaging Problem

by ALVIN C. SMITH

The warnings shown on this page are the familiar tags seen on express or parcel post shipments of fragile merchandise. The same labels on an automobile would appear ridiculous. Yet we think little of placing ourselves loosely in the oversized container which is an automobile and then shipping ourselves at great speeds down the highway, around obstacles both moving and stationary. As is all to apparent from our 35,000-plus annual automotive death toll some of us are shipped into, under and through those obstacles. Figure 1 illustrates the all too frequent end result.

Can we legislate automotive accidents out of existence? To be brief, we haven't. Despite determined efforts to enforce "legal" behavior patterns and thus to cut down on the frequency of automotive accidents, the appalling record of deaths and injuries continues. That good judgment is not created by legally requiring it appears to rule out the effectiveness of additional regulation unless prohibitively restrictive.

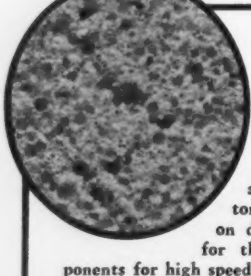
FIGURE 1

Improvements in highways and automotive performance are often proposed to "solve" the accident problem. Perhaps some reduction in accident rates can be achieved in this manner although it appears that this approach tends to defeat itself. Increased performance capabilities result in higher speeds and accelerations which in turn require greater reliance on brakes, steering and human judgment. This latter factor is probably the one which tends to offset any improvement trend which would be expected to result from improved performance.

PACKAGING PAYS OFF

As previously pointed out, efforts are being put forth to decrease the **frequency** of automotive accidents with undoubtedly some, but not startling, results. What then can be done about alleviating the **effects** of automotive accidents? There is good evidence, derived to a large degree from research on aircraft safety, that the disastrous **effects** of accidents can be substantially alleviated by improvements in the design of the vehicle itself. Available data indicate that most automobile accidents occur with impact velocities of 40 miles per hour, or less. Work on airplane crash safety has indicated that the human body can readily be protected from death or serious injury for crash velocities of that magnitude. It is therefore quite conceivable that, if adequate effort were applied to the problem of alleviating the effects of automobile crashes, the injury and death rate might be drastically decreased.

If we consider the shipment of fragile merchandise, we find that no difficulty is experienced in safe packaging. For example, even eggs can be packaged for safe shipment if reasonable handling rules are observed. Similarly, automotive packaging rules can be established for the human body which, if followed, will greatly alleviate the effects of crashes.



The photo insert appearing at the left, as well as at the top of the cover page, is a close-up view of a heat resistant, foamed plastic developed at Cornell Aeronautical Laboratory. For the past few years a substantial block of the Laboratory's plastics research has centered on developing materials and techniques for the sandwich construction of components for high speed aircraft and missiles. Very recently a program for the Air Force was completed that involved the development of a high strength, heat resistant core material that can be foamed in place. As a result a foamed plastic material, pictured here, has been developed that is being produced commercially for use in foamed-in-place structures requiring resistance to elevated temperatures. Prepared from unsaturated alkydtriallyl cyanurate copolymeric resins, this foam maintains its physical properties in sandwich structures at 400°F. Other foams generally lose nearly all their strength when heated to about 200°F. In order to allow for high frequency electrical application, foams of eight to ten pounds in density were studied. The density of the foam pictured here is ten pounds per cubic foot.

As demonstrated by stunt men, the human body can be "packaged", if safety is the **only** consideration, to allow even a ride over Niagara Falls. However, although the automobile has a prime utilitarian purpose of personal transportation, it has also become an instrument with social significance. As such, styling, comfort and operational convenience are factors which cannot be ignored. Modification of the automobile for "safer packaging" of the occupant must therefore be judiciously planned.

"Safer packaging" of the human occupant of an automobile may be achieved by either one of two methods: body restraint which prevents damaging impact with interior components of the automobile or reduction of the lethal or injury potential of the objects which the body (with principal emphasis on the head) might strike. Maximum protection is afforded by a combination of the two. Research is being conducted relative to both methods. Sponsorship of various phases of the investigation in progress at the Cornell Aeronautical Laboratory has come from several sources: the Liberty Mutual Insurance Company, the United States Rubber Company, the Hickok Company and a major automotive manufacturing company. The various phases of the research thus sponsored, although dealing with different facets of the overall problem, have one main objective of how to "safer package" the occupants.

BODY RESTRAINT VITAL

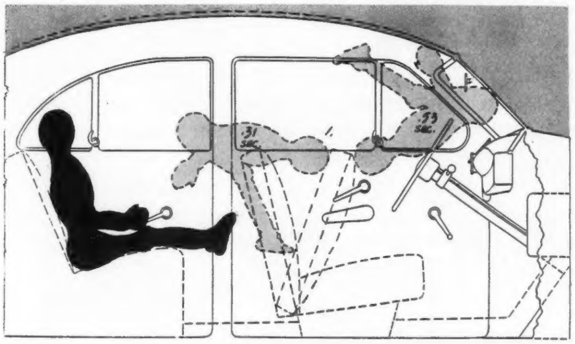
The automobile safety research which forms the basis for this article is not the only effort in this field being put forth by the Cornell "family". The Cornell Aeronautical Laboratory is a member of a Cornell Committee for Transportation Safety along with the Campus at Ithaca and the Crash Injury Research Group at the Cornell University Medical College in New York City. The work of this committee involves research into virtually all aspects of the problem of relieving the effects of automobile and aircraft accidents.

Extensive investigation in the field of aircraft safety has established conclusively the value of body restraining devices such as seat belts and shoulder harnesses during crash level decelerations. Although the combination of seat belt and shoulder harness is the optimum restraining device, it is recognized that the shoulder harness would not be acceptable as a piece of equipment for automotive use at the present time. The lap strap type of seat belt similar to that used by the commercial airlines would be, however, a very valuable accessory. Its life-saving ability has been repeatedly demonstrated in aircraft use.

The seat belt has the primary function of restraining the body from moving forward relative to the vehicle when the vehicle is decelerated at a rate beyond which the human can normally restrain himself. Although the basic intent is to prevent the body from striking some lethal object, it has been found that above a certain deceleration level, even with a seat belt, the passenger (from some positions) can strike his head against certain objects within the car. With the seat belt in use, however,

only a **portion of the kinetic energy** of the body can contribute to the head blow. Without restraint, the **kinetic energy of the entire body** can contribute to the magnitude of the head blow.

Although the Cornell Aeronautical Laboratory, Inc., has not completed detail engineering on a seat belt design, certain design criteria have been established. For



Typical action of "Half Pint" with and without a seat belt during a crash test. These line drawings, based on experimental data, represent the dummy's behavior during a crash test run at 20 miles per hour. The car was brought to a stop in slightly less than four feet, or at a deceleration of about 3.5 g.

example, the static strength of the belt assembly in tension, including webbing, buckles, fittings, etc., should be a minimum of 1,500 pounds (3,000 pound loop strength). The width of the seat belt, including any component in contact with the person, should not be less than two inches.

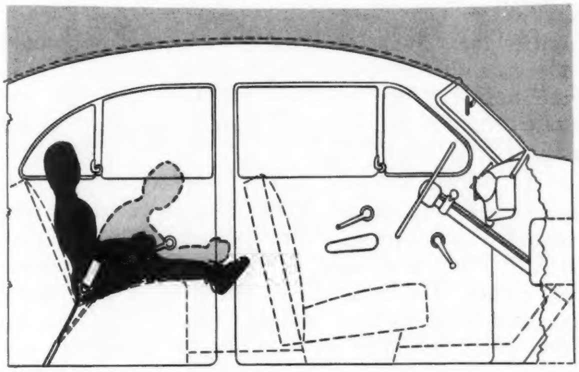
An important point in the use of a seat belt is that it is not necessary to pull a seat belt tight against the body to be effective. It was found from experimental tests that little change in the effective action of a belt is incurred when it is adjusted to allow approximately a 3- to 4-inch forward motion of the hip joint.

"MUSTS" FOR SEAT BELTS

There are many methods of attachment of the seat belt to an automobile that are completely satisfactory, providing certain design requirements are satisfied. The seat belts should be arranged with one person per belt so that both lateral and longitudinal restraint is provided to the wearer. The seat belt must be attached to the primary structure of the car to insure adequate anchorage. The individual attachment fittings, and the part of the car to which each fitting is attached, must be capable of withstanding a minimum of 1,500 pounds pull force without failure or appreciable deformation in order to be consistent with the belt strength. The seat belt installation should be designed so that the line of restraining force makes an angle with the horizontal of from 30° to 60° so that the restraining force is confined to the bony structure of the hip joint.

A universal "do it yourself" seat belt kit currently is being designed by C. A. L. under the sponsorship of the Hickok Company and should be available commercially within a few months.

It is recognized that there may be some apathy, or even resistance, of the public toward the installation and use of seat belts. In view of this, alternate methods of body restraint are being explored, such as pull-out panels, crash bars and special seat designs. Unfortunately, most of these types of designs are restricted to the car of the future because they require major redesign of the vehicle itself. We believe, however, that equipment of this nature will ultimately be incorporated. When this will occur will be largely a function of



how soon and how strongly we, the public, manifest our desires for safer automobiles to the manufacturers.

In recognition of the points that optimum provisions for body restraint probably will be slow in coming and that seat belts may not be universally accepted, a program was laid out and is now in progress to investigate what could be done to reduce the crash hazards of the present automotive interior. Since the majority of passenger fatalities are a result of head blows, principal emphasis is being placed on protection of the head.

The program is seeking first to estabilsh the relative hazard to the head of the various components which make up the interior of the automobile forward of the occupants; and second to establish, by design studies, the recommended configuration of the automotive interior for optimum safety.

The relative hazard to the head of any forward interior component of the automobile is believed to be a function of three variables: **the relative probability of head impact** to that component, **the relative energy of impact,** as influenced by the attitudes and posture of the body at the instant of impact, and the angle of the blow to the object and **the relative injury potential of the component,** as influenced by shape, mass and mounting resilience.

One of the phases of investigation which contributed heavily to the data required for determination of values for the first two of these variables is described in the following paragraphs.

Where are the occupants of an automobile likely to strike their heads when the automobile is subjected to crash level decelerations? What are the posture, atti-

tude and flight path direction relative to the automobile at the instant of head impact?

CRASHES THAT AREN'T ACCIDENTS

Although it might be possible to answer the above questions by "common sense" inspection, the answers can only be of a speculative nature. It was also apparent that if parameters influencing the motion of both the occupant and the vehicle are recognized, defined and evaluated, analytical solutions would be possible although exceedingly complex. It was decided that experimental evaluation under controlled laboratory conditions would result in a more immediate and positive answer.

Obviously live subjects could not be used, nor would it be economically feasible to crash and destroy a car in each test. The first step was therefore to devise test equipment that would permit proper simulation of the desired crash conditions.

A friction snubbing device was constructed for inducing a longitudinal decelerating force to the test vehicle. This apparatus is shown schematically in Figure 2. A 200-foot steel cable, along which the test vehicle was guided, was fastened to a flat strip of sheet metal clamped between two wooden blocks. The friction force could be varied by adjusting the clamping pressure on the slider plate. The cable passed freely through a hole in a stop plate installed on the front end of the test vehicle until the cable-end collar was reached.

REUSABLE PASSENGERS

Additional modifications to the test vehicle included provisions for remote steering, remote ignition cutoff (safety and desired test condition), external throttle control (speed control), auxiliary lighting (for photographic purposes). The left hand door was replaced with a reference grid for determining the "passenger" position during the crash.

The "passengers" consisted of two dummies, one adult sized and the other equivalent to a six-year-old child. These dummies, shown in Figure 3, were constructed to be dynamically similar to their human counterparts so that they would duplicate the motion of an actual person under similar circumstances. The location of each dummy within the car was varied from test to test.

In the simulated crash tests, the impact condition selected was one equivalent to front end bumper level contact while applying full braking. A stopping distance of 1.5 to 3 feet from an onset velocity of 10 to 20 miles per hour was controlled for the majority of the tests. Although the conditions selected were somewhat arbitrary, they represent typical conditions which it is possible to encounter in a highway accident and were within the structural limitations of the equipment utilized.

CONTROLLING THE CRASH

The launching of the unmanned test car was accomplished as follows: with rear wheels raised from the roadway with a hydraulic jack, the engine was throttled to an indicated speedometer reading of approximately 10 miles per hour (transmission in low gear). On a prearranged signal, the hydraulic jack was lowered. A crewman ran alongside the car for 10 to 15 feet, during which time he pulled the throttle to a previously adjusted maximum setting which was calibrated to give the desired onset velocity.

A 16 mm camera was set up so that the field of view covered the passenger compartment from the beginning to the end of the snubbing action. The camera speed was set for 64 frames per second. A controlled blinking light was located in the foreground to supply a time reference. Vertical rods were set up adjacent to the stopping ramp to supply a convenient fixed space reference.

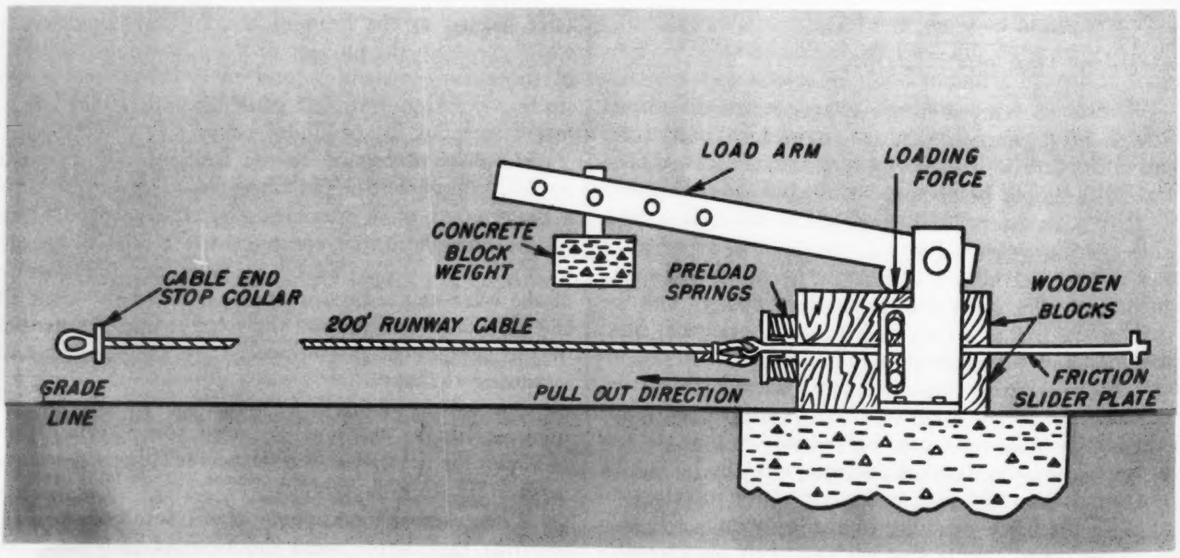


FIGURE 2 — Schematic drawing of friction snubbing device for bringing the test car to a "crash" stop.

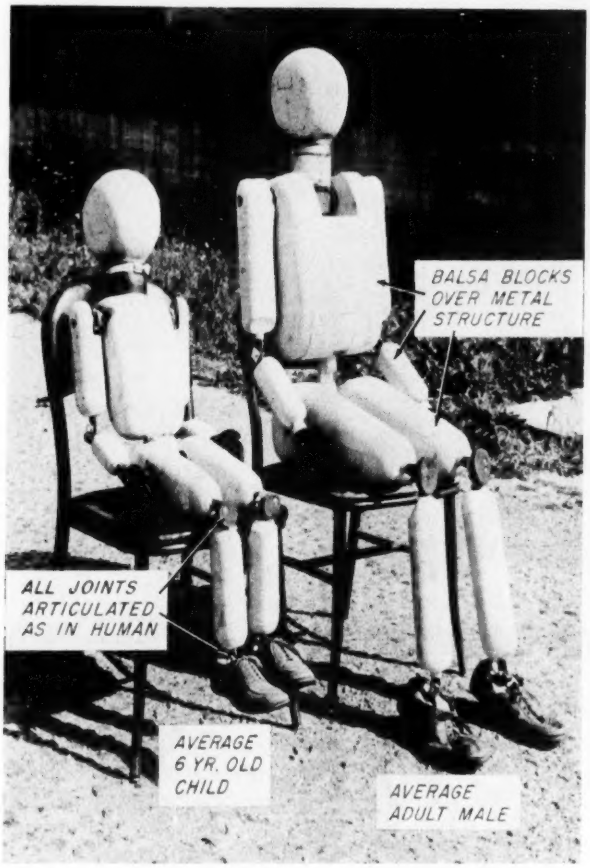


FIGURE 3 — Half Pint and the Thick Man — "human" passengers used in the auto crash tests.

The time-motion history of the test vehicle and dummies was established by a frame-by-frame inspection of the motion picture film. The motion of the vehicle with respect to fixed references and the motion of the dummies with respect to the vehicle were transcribed and recorded against time.

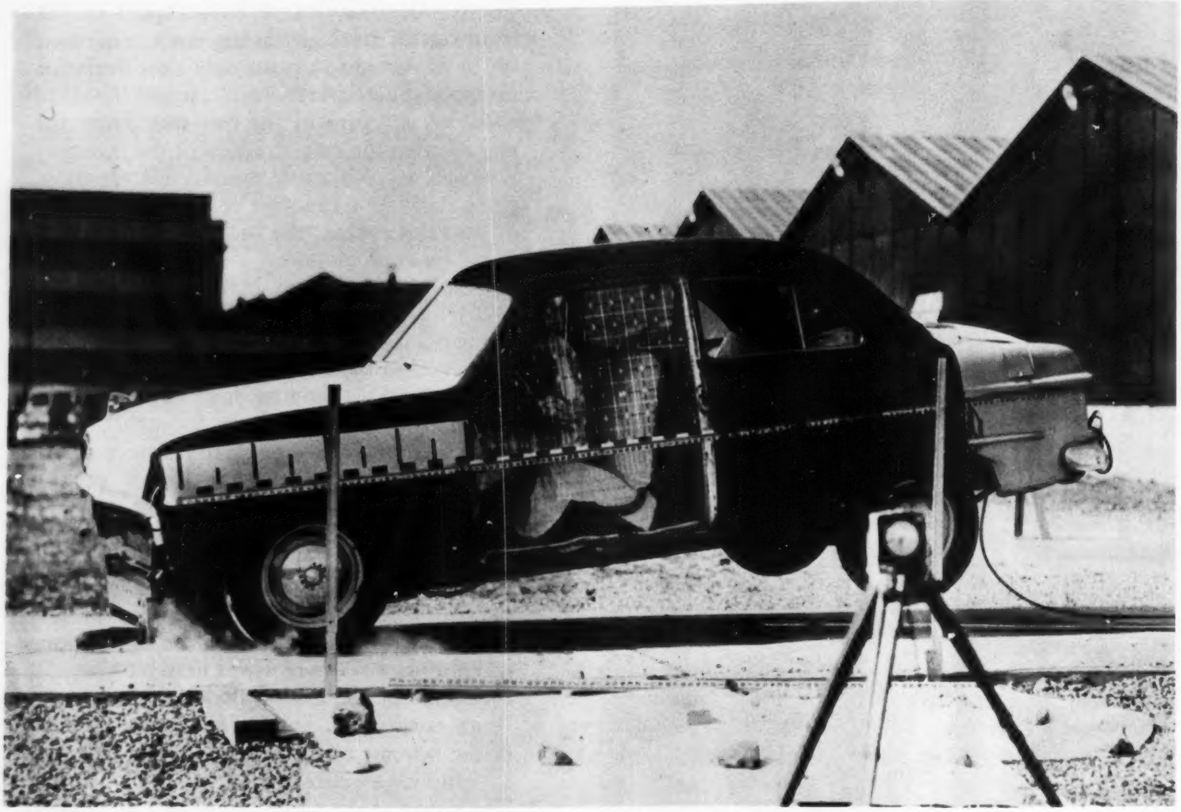
THE TESTS TOLD US THIS

Although the number of snubbing tests which have been conducted thus far is not large enough to allow a true statistical analysis, the data obtained do allow certain conclusions to be drawn. These are presented along with several observations which may be of special interest.

1. The actions of both the test vehicle and the dummies relative to the vehicle were extremely violent even though the maximum average deceleration for any test was 3.5 g and the maximum peak deceleration recorded was 4.6 g.
2. It is possible to predict the **initial** motion of an occupant of a vehicle during a crash providing the vehicle deceleration and motion is known.
3. The terminal motion of an occupant of the **front seat** of a vehicle during crash conditions can be predicted to a reasonably close degree of accuracy. Such a statement cannot be made about an occupant of the **rear seat.** From the rear location the specific action of the occupant is violent and subject to considerable variation, particularly as a function of whether he does or does not contact the back of the front seat in his forward motion.
4. For front end collisions, there is a definite, definable, probable initial hit area for the head of the occupant of the vehicle. Exclusive of the area screened by the steering wheel, it includes a vertical area extending downward from approximately one foot aft of the upper windshield molding (on the roof) to the midpoint of the instrument panel. Laterally, it extends from front corner post to corner post inclusive.
5. In a front end collision, the driver will invariably receive a potentially injurious blow to the torso against the steering wheel. If the magnitude of the deceleration is above approximately 2 g, the driver, if not impaled on the steering wheel post, will also receive a head blow against the upper windshield or windshield molding.
6. In an essentially front end collision, the sides of the interior of the vehicle do not represent a serious injury potential.
7. The action of the occupant consists of rotation of the upper torso about the hip joint accompanied by an upward and forward acceleration at an angle of approximately 45° relative to the car. For an adult in the right front seat, the head initially strikes the upper windshield molding region. Upper torso rotation continues and a secondary head blow (usually glancing) against the windshield results. The action is generally terminated by a facial blow on the upper instrument panel shelf. The action of the adult and the child from any position in the car may be similarly defined.
8. An examination of the final resting position of the dummies after the crash was found to be an inadequate method for determining the time-motion history of the dummies during the simulated crash. Rear seat occupants frequently ended up in the rear compartment although the photographic records disclosed that they had traversed the length of the compartment—rear to front and then back again.

"LONG WAY TO GO"

As can be seen from this brief review of the Laboratory's auto safety research, the premise on which it is based is one of recognizing that automotive accidents will continue to occur in spite of either legislative action or performance improvements. Although we join in the high hope that more effective legislation and improved



Auto crash test vehicle at peak of impact.

automobile performance will yield substantial benefits, we believe that the greatest immediate gains in combating highway deaths can be made by protecting the individual when an accident does occur. This approach is of relatively recent origin and still has a long way to go to realize its maximum benefit. To date, however, the results have been extremely encouraging and seem to promise a day when accidental deaths due to automobile crashes will be a rarity rather than the common everyday occurence that they are now.

"Automobile crash safety research," Smith, A. C., C.A.L. Report YB-846-D-1 (149 pages)

"Protection of the human head from blows delivered by a flat surface," Dye, E. R., SAFETY EDUCATION (April 1953)

TITANIUM

by **L. W. SMITH**

Since the birth of ductile titanium, commercially, in 1947 a tremendous amount of scientific and technological effort has been expended on titanium at a cost of many millions of dollars. Seldom before has there been so much research directed in so short a time to a single industrial metal.

Contrary to the belief of some of its early and avid proponents, titanium is not a wonder metal destined to replace all other materials. On the other hand, it does possess a number of very attractive physical and mechanical properties which are important enough to justify the highly intensive research effort that has been spent over the past seven years in an attempt to establish this new metal's rightful place in the line-up of engineering materials. For example, as shown in Figure 1, the strength-to-weight ratio of titanium and its alloys at 700° to 800°F far exceeds that of aluminum, and even at room temperature this ratio is not too inferior to that of either aluminum or steel. Titanium has also demonstrated outstandingly good resistance to corrosion, superior in a number of environments to that of alloy steels and equal to or better than that of stainless steels. Its modulus of elasticity is greater than that of aluminum but below that of steel, while, as shown in Figure 2, its density lies about half way between aluminum and steel. Viewed in this light titanium is another engineering material of importance in critical uses, especially at service temperatures between 200° and 750°F. In aircraft it is currently replacing aluminum in some applications and stainless steel in others.

ABUNDANT SUPPLY

Titanium ore is abundant throughout the world and North America itself has a sufficient supply of this ore to match present production levels of other basic metals. In actual quantity, titanium is the ninth most abundant element and comprises about 0.65 per cent of the earth's crust. The two most important sources are rutile (titanium dioxide) and ilmenite, a ferrotitanate. Ample deposits of ilmenite are found in New York, Florida, the Carolinas, Idaho and in Canada. Rutile, though not as plentiful, is present in substantial deposits in Virginia.

The illustration on page 8, as well as Figures 1 and 3 accompanying this article, have been reprinted courtesy of the Westinghouse Engineer.

The method by which practically all titanium is now being produced industrially involves esentially a chlorination process of titanium oxides with subsequent reduction by magnesium that yields, finally, a coke-like mass of metallic sponge. The sponge is then broken up and ground to a suitable size for melting. The selling price of the sponge at this stage is about $4.75 per pound. Comparable costs of steel and aluminum at this stage are 3 cents and 22 cents, respectively.

All of the major problems connected with the extraction, melting and fabrication of titanium stem from its very highly reactive properties when hot, particularly when molten. It has a great affinity for oxygen, and since even small traces of this element have a marked embrittling effect on the metal, production

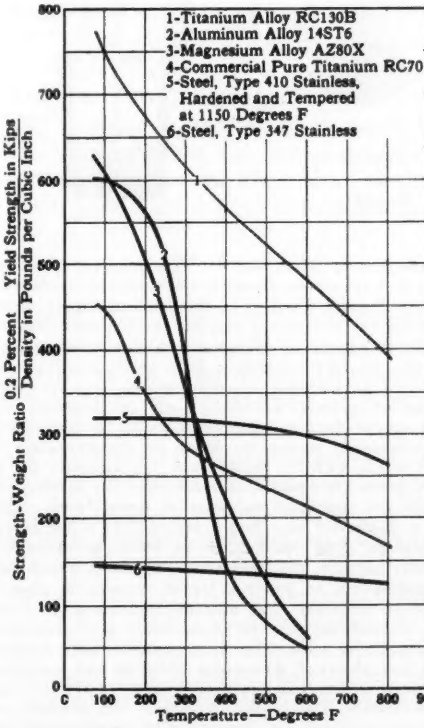
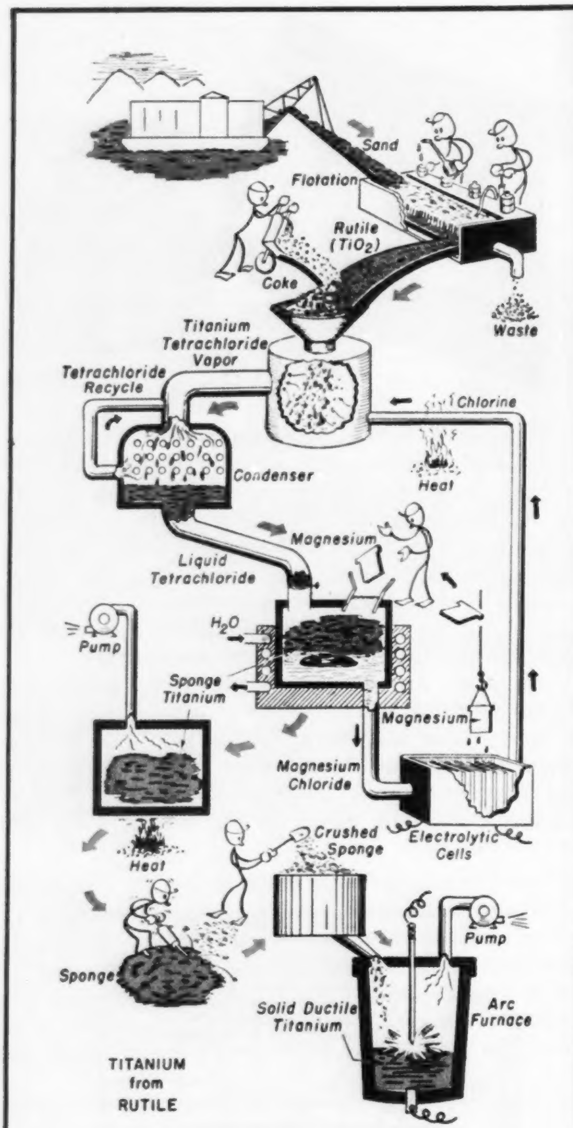


FIGURE 1 — Chart of high temperature strength properties of titanium, aluminum and steel.



From Ore to Titanium — The principal titanium-bearing ores are rutile, ilmenite, arizonite and titaniferous magnetite. Rutile, which is in the smallest supply of the four, is also the richest, the simplest and the most desirable from the standpoint of titanium recovery. Although the production of ductile titanium from rutile is still undergoing rapid development, the steps shown here are representative of present practice. Sands in Australia and Florida are dredged and processed by water flotation or other mechanical means to obtain an approximately 90 percent rutile (TiO2) concentrate. On exposure to hot chlorine gas in the presence of carbon the tiny black grains of rutile are converted to titanium tetrachloride vapor, which is condensed to a liquid and sent to a batch-type, heat-resistant steel reactor. In an inert-gas atmosphere (generally helium), the tetrachloride reacts exothermically with magnesium to produce liquid magnesium chloride and sponge titanium. The magnesium chloride is drawn off to electrolytic cells for dissociation into magnesium and chlorine for reuse. The metal crucible, with titanium sponge and absorbed magnesium chloride and unutilized magnesium, is removed and heated to drive off the magnesium chloride. The sponge is chipped out, crushed, and fed to an inert-gas arc furnace. The sponge melts and solidifies as a solid ingot suitable for forging.

Reprinted courtesy of Westinghouse Engineer

processes thus far developed have had to start with oxygen-free compounds of titanium. Further, because of the solubility of nitrogen and oxygen in titanium, and because the molten metal attacks all the known materials used either for lining metal-melting furnaces or in the construction of crucibles, it has been necessary to develop special equipment and procedures for melting titanium in a vacuum or in argon gas. As a result, the melting of titanium is at present a costly and time-consuming operation and, on this basis, compares unfavorably with other metals in common industrial use.

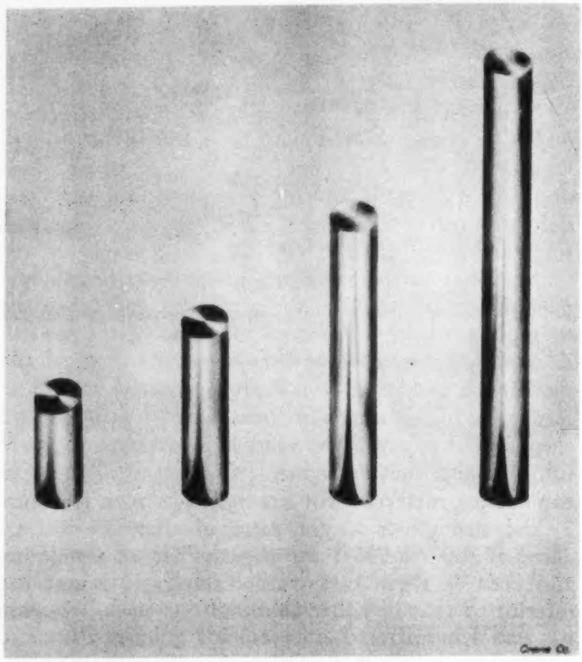


FIGURE 2 — Relative density of stainless steel, titanium, aluminum and magnesium. Each bar weighs one pound.

As might be inferred from the magnitude of the problems sketched above, current production of titanium is very small. In fact, the United States appears, at present, to be the sole producer of the metal, although a small amount of experimental work with titanium is under way in a few other countries. The total titanium output this year is expected to be only about 0.35 per cent of aluminum but about 12 per cent of the magnesium production. Despite the relative smallness of this figure, it represents a sharp increase over the production levels of previous years. Currently the producers of titanium sponge are E. I. duPont de Nemours and Company, Titanium Metals Corporation of America, U. S. Bureau of Mines and Cramet Company.

The melting of titanium sponge and the subsequent shaping of the metal into bar and sheet stock is generally considered a separate operation in the processing of titanium and, with the exception of the Titanium Metals Corporation, involves other than sponge-producing companies. In addition to Titanium Metals, the other companies engaged in this work are Rem-Cru Titanium Inc., Mallory-Sharon, and Republic Steel.

When titanium production left the pilot stage and mounted to sizeable tonnages, substantial price reductions were forecast which up to now have failed to materialize. True, the present price of wrought titanium (titanium in cast form has not been developed commercially to date) is a far cry from the $3,000 per pound that samples of ductile titanium sold for in early 1947, but it still remains that no significant price reductions have been realized over the past few years despite rather substantial increases in production tonnages. Some small reductions have been effected recently but, for other than special uses, titanium cannot compete, at present, with other materials on a cost basis. For example, the current price for mill shapes of titanium, such as round and flat bars, is ten to fifteen dollars per pound while sheet stock is selling from twenty to twenty-five dollars per pound. These figures are comparable with less than one dollar a pound for mill shapes or sheet stock in steel and aluminum. In addition, the nonuniformity in the properties of delivered titanium has been resulting in a rejection rate many times that of steel and aluminum, thus pushing the over-all cost of the metal still higher.

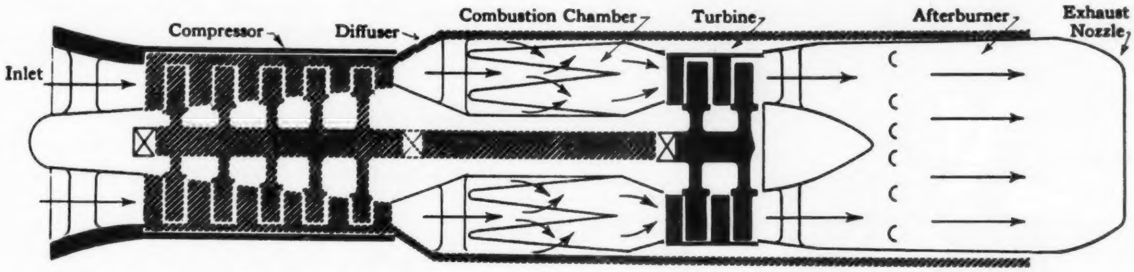


FIGURE 3 — PLACE FOR TITANIUM is indicated in this jet engine cutaway. The cross-hatched section shows where the metal has been used or has been investigated—in compressor discs, compressor blades, compressor stators, bolts, compressor and turbine liners, and sheet metal parts. New alloys are expected to increase titanium's heat advantage over steel.

PARADOX

As if the acute problems inherent in the production of titanium were not enough, a paradoxical supply problem has now emerged to further complicate an already complicated picture. A year ago there was a shortage of titanium. Today the consumption of titanium is lagging behind production. There are several reasons for the temporary oversupply condition that exists at the moment. First, current sponge production methods and expansion programs have resulted in quick jumps in the production level of titanium rather than a steady, even increase. In addition, there are as yet no general or high-volume uses for titanium principally because titanium is still pretty much of an unknown factor in production. The only real consumer today is the aircraft industry and here the general practice has been to use titanium to make small parts or a few large parts in order to gain experience with the metal without becoming dependent on it for production schedules. Actually, all of the titanium scheduled for production this year could conceivably be used by a single airframe or jet-engine manufacturer if full conversion to the metal was made. In this light, the reluctance of the aircraft industry to rely heavily on titanium is understandable and this reluctance will probably continue until titanium production substantially exceeds the current level.

There appears little reason to doubt, however, that, given time, titanium will find widespread application in the aircraft industry. Already it is being used on a modest scale by both airframe and jet-engine manufacturers, with the prospect for much more concentrated usage once production rates reach more adequate levels. Figure 3 shows various applications titanium is finding in the construction of jet engines, including its use for such items as compressor discs, spacer rings and compressor blades. Some titanium in unalloyed sheet form is also being evaluated for shrouds and ducts. As a whole, the manufacturers of gas turbines for aircraft appear to be confident of improving their powerplans through the use of titanium. Before this improvement can be reached, however, considerable research and development effort will have to be expended in improving the strength and ductility of titanium alloys and in overcoming the wide variance in mechanical properties that characterizes much of the titanium being produced today. Additional fundamental knowledge will also be needed on the metallurgical aspects of titanium forgings since the major share of titanium for gas turbines will be in the form of forged shapes.

MEETING A NEED

In the airframe industry titanium is currently finding two general areas of application. In fire seals, unalloyed grades of the metal are being used as a substitute for stainless steel on a gage-for-gage basis. No high stresses are involved in this use and the favorable flame and heat resistance of titanium compared to that of stainless steel constitutes an important advantage. The second general area in which titanium is being used is for structural members that are subjected to slightly elevated temperatures, for example, around the exit end of jet engines. In such locations the temperature exceeds 250°F, which is usually considered the top working temperature for aluminum alloys but is below 600°F where the strength of titanium begins to fall off rapidly. When the parts involved in such applications are stressed members, alloy titanium is customarily used because of its higher strength. Figure 4 shows possible applications of titanium in a typical fighter aircraft.

In addition to the uses indicated above, titanium may provide the answers to two of the main problems that are currently confronting the designers of supersonic aircraft. Excessive heating of aluminum wing surfaces and fuselages can be expected as design speeds are pushed upwards. Titanium, because of its excellent strength properties at high temperatures, may well replace aluminum in such applications. In the development of new turbojet engines that will be needed to power the high performance aircraft of tomorrow, weight is certain to be an extremely critical item. In

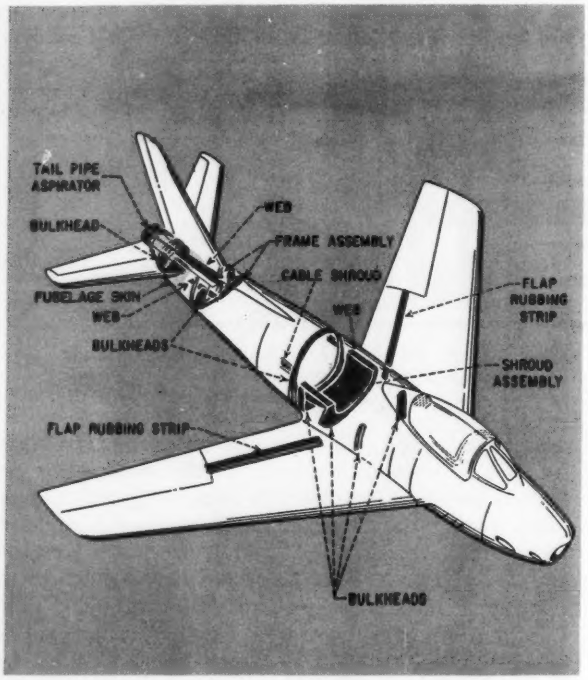


FIGURE 4 — Typical uses of titanium in a jet fighter.

this regard, the substitution of titanium for steel may prove to be a particularly feasible means of circumventing this problem of increased weight.

MORE PROBLEMS

Earlier in this article, a brief discussion was presented of some of the major difficulities being encountered by the producers of titanium. As might be expected, these difficulties have produced their counterparts in the aircraft industry, only in this case the titanium problems are ones of use rather than production. At the request of the Air Force, Cornell Aeronautical Laboratory has just completed an extensive survey of the applications that titanium is finding in the aircraft industry with the aim of determining the problems being encountered and of formulating a research program to resolve these problems. The results of this survey indicate that three problems appear to be of the greatest concern to the industry. First, a wide variance has been noted in the mechanical properties of both unalloyed and alloyed titanium sheet. In some instances the spread between yield and ultimate strengths has been found to vary markedly. Because forming difficulties are usually encountered when the spread is small, it is highly desirable to have this spread large and uniform. Another aspect of the same general problem has been the large spread in strength properties encountered from one heat to another in the same grade of titanium.

WHAT'S THE ANSWER

A second problem that is causing concern in the industry involves the use of titanium forgings for airframes. Several airplane manufacturers have found that such forgings, whether partially machined or unmachined, exhibit very poor fatigue characteristics. On the other hand, engine manufacturers make wide use of completely machined forgings with apparently satisfactory results.

The final industry-wide problem uncovered hinges on proper procedures for eliminating the residual stresses produced by machining and forming methods employed in the fabrication of titanium aircraft parts. The situation on this point is confused. Several aircraft manufacturers have reported a decrease rather than an increase in the endurance strength after their parts have been stress relieved. Some manufacturers do not stress relieve unalloyed titanium after hot forming while others do. Cracking of alloy sheet after assembly has been reported even though the titanium was given a stress relief treatment after forming.

All of the above problems have been reviewed with titanium producers in an effort to explore what can be done to resolve the difficulties involved. Although it

The Douglas DC-7 airliner was the first commercial airplane to utilize titanium. Through the substitution of titanium sheet for the aluminum alloys and the stainless steel normally used as skin materials for the engine nacelles, a weight-saving of about 200 pounds per airplane was effected. Unalloyed titanium was also used in the construction of the airplane to replace the stainless steel customarily employed for firewall webs.

is already apparent that there will be no royal road to success in this undertaking, the outlook for the solution of all of these problems looks reasonably bright.

FINDING ITS PLACE

It is important to keep a sense of perspective in evaluating what the future holds for titanium. Certainly it is not a wonder metal, a universal material that is to replace all other materials, as many of its early advocates claimed. On the other hand, it is much too soon to write off the very solid virtues that titanium definitely possesses simply because these virtues cannot be had merely for the asking. Virtue has never been an easy thing to come by. It must be remembered that the titanium industry is young, and that despite broad increases in knowledge concerning the behavior and use of titanium, seven years is just too short a time to expect to lick problems as formidable as those involved in developing satisfactory techniques for the production and application of this new metal. Substantial effort is, however, being brought to bear on these problems. Improvements in titanium melting procedure are being evaluated to determine whether additional homogeneity can be gained by double melting the heat, or by the so-called skull melting process which permits the casting of heats as one complete molten batch rather than a continuous series of molten pools, as is essentially the case with the present arc melting technique. Attention is being devoted to the development of faster and cheaper methods for analyzing titanium and its alloys for the quantity of dissolved gases, particularly oxygen. Investigations are also in progress to ascertain the effect that quantity and type of dissolved gases have on the properties of titanium. New alloys of titanium are under development in an effort to obtain added strength with good ductility at room temperature and to extend the present high-temperature limits of titanium. A wide range of studies is under way aimed at improving current fabricating procedures for the forming, joining and machining of titanium. The utilization of scrap titanium is under intensive investigation as a means of both lowering the cost and making additional titanium available. Within the next few years, it appears reasonable to expect that from these and other studies will come the answers to many of the perplexing difficulties that, at present, are preventing titanium from finding widespread application in industry.

REPORTS

"Strength of joints in titanium brazed with several alloys," Smith, L. W. and Yerkovich, L. A., PRODUCT ENGINEERING (July 1953).

About the Authors...

ALVIN C. SMITH. Mr. Smith has been responsible for about forty automobile crashes. To his credit it must be said that no human injuries or fatalities have resulted. Mr. Smith is project engineer of the Laboratory's automobile crash research, and he hopes that information gained from these crashes may some day be instrumental in reducing the toll of injuries and deaths resulting from automobile accidents.

After nine years with the Curtiss-Wright Corporation both in Buffalo, New York and Columbus, Ohio, with experience in flight test engineering and power plant analysis, Mr. Smith became a member of the C.A.L. family in 1950 as a member of the Development Division. He was initially assigned to an aircraft vulnerability project studying air flow and heat transfer problems within aircraft structures. His first taste of automotive research came in 1951 when he performed work on an automobile steering system to reduce the complexity and cost of that unit.

He joined the Industrial Division at its inception in late 1951 when the Laboratory formed that Division in order to devote increased attention to the research needs of general industry while still maintaining its primary emphasis upon aeronautical research for the military. From its outset, automotive safety studies have been a core activity for the Industrial Division.

Mr. Smith received a Bachelor of Science degree in Aeronautical Enginering from Tri-State College. He carried out additional undergraduate and graduate study at Ohio State University. He is presently a member of the Institute of the Aeronautical Sciences.

LOREN W. SMITH. The so-called "wonder" metal, titanium, holds no wonders for Mr. Smith, head of the Metallurgy Section of C.A.L.'s Materials Department. The two are intimate associates and in the past few months have virtually lived together.

As part of his Section's various efforts on titanium research, Mr. Smith very recently surveyed the aircraft industry and titanium producers throughout the nation. He did this as part of a U. S. Air Force sponsored project aimed at determining the problems encountered in the application of titanium in aircraft and at formulating a research program to resolve these problems. In addition, Mr. Smith is a member of the Titanium Research Panel of the Minerals and Metals Advisory Board of the Department of Defense.

Mr. Smith has been with C.A.L. since 1946. Previously he had served with Curtiss-Wright Airplane Division both in the production plant and the Research Laboratory—forerunner of C.A.L. He has had experience with Chevrolet Motor Corporation, Linde Air Products, E. I. du Pont de Nemours & Company, and American Radiator Corporation.

Mr. Smith received a Bachelor of Science degree in Chemistry from Canisius College and has done graduate work at the University of Buffalo. He is presently a member of the American Society of Metals, and served as director of the local chapter in 1947 and '48. He was a conferee to the First World Metallurgical Congress in 1951. In addition to his post on the Titanium Research Panel of the Minerals and Metals Advisory Board, Mr. Smith is also a member of the Guided Missiles Panel of that group.

Recent C. A. L. PUBLICATIONS

Requests for copies of the following unclassified reports should be directed to the Editor

"A FLIGHT DATA COMPUTER," Bogdan, L., National Conference on Airborne Electronics, Institute of Radio Engineers, Dayton, O. (May 1954)

A paper on an integrated instrumentation system for airplanes which provides, from one compact source, outputs of true angle of attack, sideslip, airspeed, relative air density and Mach number.

"A METHOD FOR GENERATING STRONG SHOCK WAVES," Hertzberg, A. and Smith, W. E. *Journal of Applied Physics* (January 1954)

A discussion of a simple modification of the operation of the combustion-powered, high-pressure-ratio shock tube.

"APPLICATION OF MONTE CARLO TECHNIQUES TO THE ANALYSIS OF THE GROUND CONTROLLED APPROACH (GCA) SYSTEM," Blumstein, A., C.A.L. Report JA-848-G-2 (80 pages)

The problem was to determine the distribution of airplane positions along the flight path. A mathematical model of the GCA system was prepared, coded for computation by the Monte Carlo method, a numerical analysis technique, and the resulting positions determined.

"DESIGN OF PREDICTION FILTERS," Fleck, J. T., National Conference on Airborne Electronics, Institute of Radio Engineers, Dayton, O. (May 1954)

The theory of the design of linear predictors for low frequency signals is discussed; Wiener's methods for obtaining the transfer function of the prediction filter are employed; important steps in the design of prediction filters are summarized.

"ELECTRONIC SIMULATORS FOR STUDY OF AIRCRAFT FLIGHT PATHS," McDonough, S. L., National Conference on Airborne Electronics, Institute of Radio Engineers, Dayton, O. (May 1954)

Several methods of simulating simplified aircraft tracks in three dimensions are described; methods vary in the degree of aircraft maneuverability from non-maneuverability straight-line aircraft to that of fixed rate of turn aircraft.

"MEASUREMENT AND INTERPRETATION OF FLIGHT TEST DATA FOR DYNAMIC STABILITY AND CONTROL," Muzzey, C .L. and Kidd, E. A., C.A.L. Report 60 (163 pages)

The problem of selecting the type of flight test best suited to dynamic stability and control work is discussed in relation to the nature of the airplane's behavior, the flight time required, the instrumentation requirements and the ease of data analysis.

"NAVIGATION OF AIRCRAFT BY INTERMITTENT COMMANDS FROM GROUND BASED EQUIPMENT," Gnau, D. V., National Conference on Airborne Electronics, Institute of Radio Engineers, Dayton, O. (May 1954)

Although time sharing of a single ground computer to service a large number of airplanes may be good economics, the intermittency of control raises questions concerning stability, gain, noise, smoothing, etc. These questions are examined by considering the simple case of lateral control to a straight line by means of heading commands.

"PLANNING RESEARCH PROGRAMS," Furnas, C. C., American Society of Mechanical Engineers, Second Annual Engineering Management Conference, Philadelphia, Pa. (April 1954)

A paper on the plan and execution of a research program; the need to keep an objective of planning that will encourage and sustain creativity but will keep the work pointed toward a reasonably specific goal.

"THE ANALYSIS OF LINEAR SERVOMECHANISMS WITH DEADSPACE," Fink, A., University of Buffalo Thesis (101 pages)

This thesis treats discontinuous nonlinearities in simple control loops.

"THE BODY AND OGIVAL CONTOUR GIVING MINIMUM WAVE DRAG," Ferrari, C., *Atti Dell' Accademia Delle Science Di Torino*, translated by R. H. Cramer as C.A.L. Report 55 (23 pages)

The integral equation defining distribution of singularities along the axis of the body is solved in closed form instead of by a series of developments and a numerical application of this method is carried out for illustrative purposes.

"THE C.A.L. RESISTANCE SOLDERING GUN AND ELECTRONIC CONTROL," Maylott, C. F. and Naulty, H. W., C.A.L. Report ND-194-D-3 (10 pages)

A soldering gun is described that has many unique features but is based upon well-known electrical principles.

"WING-BODY INTERFERENCE AT SUPERSONIC SPEEDS—RECENT EXPERIMENTAL RESULTS AND THEIR BEARING ON ADVANCES IN THEORY," Cramer, R. H., Navy Symposium on Aeroballistics, Pasadena, Calif. (May 1952)

Experimental results are presented in such a form that the logical consistencies existing between the correlative parts of the investigation will be plainly evident, and thus easily remembered, and easily applied or extended to practical design problems.

"ZERO ELECTROSTATIC CHARGE ON AIRCRAFT," Pelton, F. M., National Conference on Airborne Electronics, Institute of Radio Engineers, Dayton, O. (May 1954)

A system was developed for maintaining an arbitrary net electrical charge on an aircraft (usually zero net charge). The system, installed on a B-29, operated satisfactorily and provided rapid control of the aircraft potential. This work was sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center under Contract No. AF 19(122)-475.

Some of the above reports require sponsor's approval prior to distribution.